Candlepower!

***David Gibson** explains lumens and candelas, and why the candlepower rating of a lamp can be misleading*

Introduction

Photometric units can be very confusing if you are not used to dealing with them. As well as a range of SI units, namely

lumen (lm)	light power flux
candela (cd)	luminous intensity (lm/sr)
illumination (lux)	incident flux (lm/m^2)
luminous emittance	diffuse reflected flux (cd/m^2)
luminance	diffuse radiated flux (cd/m^2)

there are a range of non-SI units such as the phot, stilb, apostilb, lambert and so on, which only serve to further confuse. In this note I will explain the units you are most likely to come across when reading about high-brightness LEDs for caving lamps.

The Units

Lumen

Light power (***luminous flux***) is measured in lumens. You could measure it in watts of course, but the lumen is specifically weighted to the human eye response. A watt of light power at 700nm (verging on infra-red) is much less bright than 1W at 400nm. A lumen at 700nm would be the ***same*** brightness as a lumen at 400nm, but would correspond to a ***different*** amount of power.

Candela

The unit of ***Luminous intensity***, or "brightness" is the lumen/steradian or candela (or candlepower). This is the angular distribution of the flux Imagine the light flux concentrated in a cone of variable angle. The narrower the cone, the "brighter" the light for the same power.

The SI unit of ***solid angle*** is the steradian but thinking in terms of this is difficult, so it is useful to write

$$\Omega = 2p\left(1 - \cos\tfrac{1}{2}q\right)$$

where Ω is the solid angle and θ is the angle of the cone. If θ is small and is measured in *degrees* then the expression becomes

$$\Omega \approx \frac{\pi^3}{360^2}\theta^2 \approx 0.00024\theta^2$$

which is accurate to around 2% if θ is not more than 90°.

Example

Suppose a 10 lumen source were concentrated into a uniform beam of width 4°. The resulting intensity would be over 2500 candlepower. How much power is 10 lumens? Well, a 2W halogen lamp (e.g. 4V 0.5A) is not more than 40 lm; a 2.4V 0.5A krypton bulb is about 11 lm.

Mean Spherical Candlepower

The intensity (i.e. candlepower rating) of a point source (e.g. a torch bulb) cannot be quoted because it depends on having a reflector fitted, in order to define the beam angle. However, occasionally, the intensity is quoted as if the light energy were spread evenly over a full sphere. Since there are 4π steradians in a sphere, the so-called *mean spherical candlepower* (MSCP) is simply the luminous flux (in lumens) divided by 4π .

Other Units

For a diffuse surface you cannot give a candlepower rating – The correct term is ***luminance***, measured in cd/m^2. So fluorescent lamps are specified that way, and you need to know how to convert luminance to ***illumination***. The illumination of a surface is measured in lm/m^2 or lux; and if the surface is diffusely reflective then its ***luminous emittance*** would be measured in cd/m^2. Converting the units takes some explaining – more than I have room for here.

LEDs v. Filament Lamps

Torches (flashlights) which achieve "1,000,000 candlepower" only do so by using a reflector which concentrates the light into a narrow beam.

Considering that a high-brightness LED, with a typical beam angle of 4°, might have an output of 10cd or so, you can see that filament lamps are, in fact, much more powerful. Of course, normally we spread the light from a torch over a larger beam angle so, although they are more powerful, they are not as intense ("bright"). *See my reply to Peter Ludwig's letter on High Brightness LEDs on page 30 of this issue*.

Of course, this begs the question – which is more important, a "bright" light over a narrow beam angle, or a dimmer light over a larger angle. Spotlight or floodlight? And it suggests that the candlepower of a lamp is not the only consideration – we also need to know the power rating in lumens.

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Foot-Candles

Footnotes to David Gibson's article "Candlepower" in J26

Despite what you may hear to the contrary, "traditional" high-brightness LEDs are not as efficient at turning electricity into light as are filament lamps.

That contentious statement needs some qualification. It depends, of course, on the devices with which you choose to make the comparison. LEDs are perhaps 100 times better now than early examples; and filament lamps can vary in efficiency by twenty times or more. A typical halogen or krypton flashlight bulb may be rated at 18-22 lm/W (the figure in *Candlepower* was a mistake!). A non-halogen bulb might be 6 lm/W, but even lower efficiencies, down to 1 lm/W, are possible for very small bulbs.

The "traditional" high- and ultra-bright LEDs are "bright" in terms of candela rating, but a power efficiency of under 3 lm/W is fairly typical (The units of ***candela*** and ***lumen*** were explained in *Journal 26*). A more recent "high power" LED, such as the HLMP-8100 is still only around 8 lm/W. To find an LED which is better than a good halogen lamp you need to look to the very latest LEDs – an example from Kingbright suggests 36 lm/W.

As for fluorescent lamps, the tiny 50mm 1W tubes are only 4.5 lm/W, but a typical 11W "compact fluorescent " is over 80 lm/W, and a high-efficiency 55W tube is almost 90 lm/W. The diffuse light does mean that it is difficult to compare like with like – LEDs do have their uses, but not (yet) as general cave illuminators.

The lumen output of an LED is the intensity [cd] × 0.00024 × θ^2 (θ is beam angle). This gives an approximate answer because the light is not distributed evenly; but the spill outside the beam makes up for the -3dB drop-off at the beam edge and it is good enough for a rough comparison (over 2/3 of the light is in the beam unless the LED package is diffuse). A more accurate answer can be got by inspecting the polar diagram, but you have to remember to convert beam-angle into solid angle, so it gets a bit tricky.

Reference

Gibson, David (1996), *Candlepower,* CREGJ **26**, p27, Dec. 1996

*The **foot-candle** is an obsolete unit of illumination, equivalent to 1 lm/ft^2*

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